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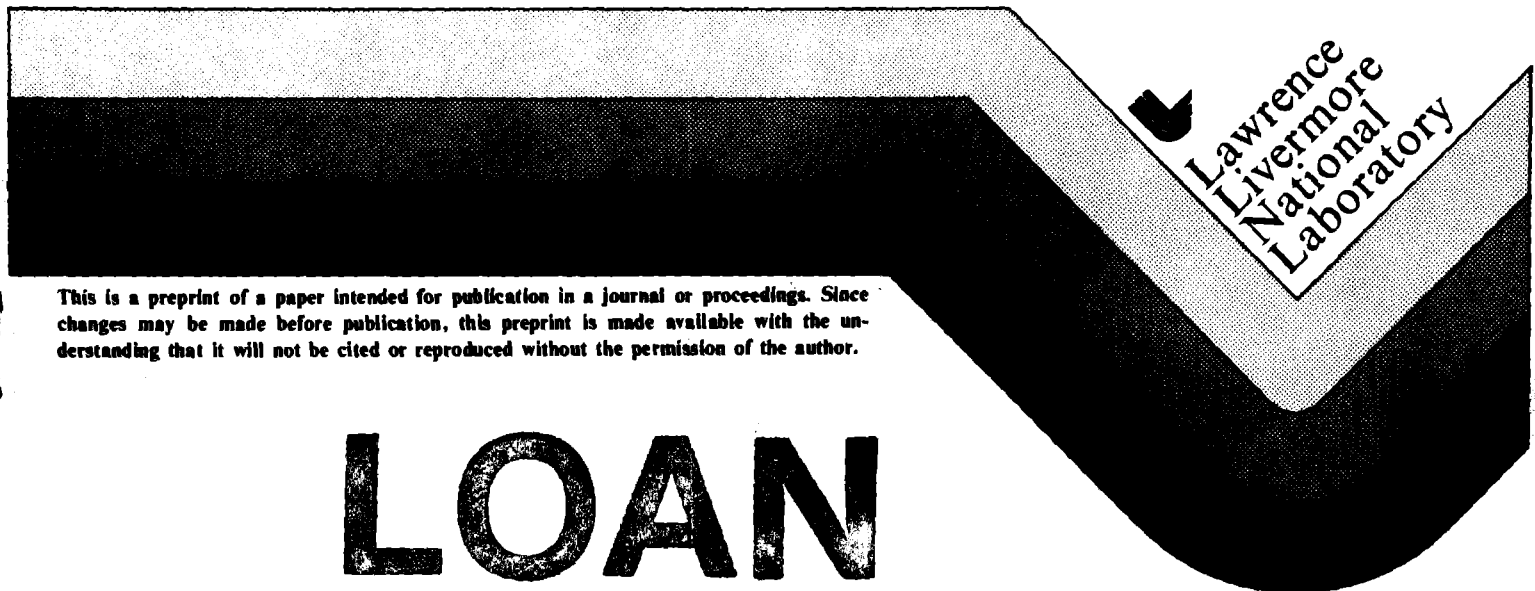
THE LLNL 150-mm EQUATION-OF-STATE GUN SYSTEM

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## THE LLNL 150-mm EQUATION-OF-STATE GUN SYSTEM\*

### ABSTRACT

Lawrence Livermore National Laboratory is currently designing a large gun system for expanded studies of a wide range of materials, including samples of high explosives weighing up to 10 kg. In its initial configuration, the system will have a 150-mm bore, 20-m-long, single-stage gun that can fire a 10-kg projectile at velocities of 2.2 km/s. Future plans include conversion either to a two-stage gun, or to a single-stage 100-mm gun, and conversion to a ballistic range. The high-explosive samples will be contained in a stainless steel tank that is 3.8 m in diameter, 12.5-m long, and 89-mm thick.

This paper emphasizes improvements in the gun design, including tube couplings that use large coupling nuts and elastic interference fits to achieve precise alignment, a rail support system that allows rapid changes of configuration without need for re-alignment, and a barrel venting experiment designed to reduce projectile tilt in free flight. In addition, the authors discuss a computer modeling experiment in which they examined the effects of stress and strain on one part of the gun, the breech. Results showed that peak stresses would cause the breech to deform, producing autofrettaged conditions.

### INTRODUCTION

Lawrence Livermore National Laboratory (LLNL) will soon construct a 150-mm bore high-velocity gun. The gun will be used in our impact tests to induce high-stress shock waves and high-strain-rate phenomena in metallic or non-metallic systems. Our studies will emphasize high-explosive (HE)-loaded-tests.

The gun will be capable of accelerating a 10-kg projectile to a velocity of 2.2 km/s in the single-stage, 150-mm bore, 20-m-long, powder-driven configuration. The target will be contained in a stainless steel tank, 3.8 m in diameter, 12.5 m long, and 89 mm thick. The tank will safely contain the blast from explosives with energy equivalent to 10 kg of TNT.

A principal design objective is to make it as easy as possible to convert the gun to a 100 mm single stage, a 150/100 mm two stage, or a long ballistics range. This objective is being met by installing a set of high-precision rails, which will support barrels, breeches, and accelerated

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reservoirs. All components can be pre-aligned to a uniform standard relating the bore to the rails, and when placed on the rails can be used without the need for a time-consuming re-alignment. Barrel sections will be coupled to the breech, and to each other, with massive coupling nuts, which will be turned by means of high torque hydraulic motors. We have used the LLNL computer code NIKE2D to model the plastic strain distribution for the breeches. The analysis indicates that, at a pressure of 690 MPA (100 ksi), plastic yielding will occur in the inner surface; i.e., the breech would deform but would not fail.

All components of this gun will be much too massive to be carried and operated manually, so an array of tools and fixtures has been designed to enhance the operation and maintenance of the gun.

The explosive energy released by the targets will destroy components located nearby. The projectile must travel up to 2 m in free flight between the muzzle and the targets, and experience minimum tilt on impact. Our objective is to hold tilt to 1 mrad after a free flight of 1 m. We studied the effectiveness of venting barrel pressure just before the projectile emerges from the muzzle as a means of minimizing random tilt in free flight.

### **THE HEAF FACILITY**

LLNL is presently building a research facility to develop new explosives and new ways to use them. The High Explosive Application Facility (HEAF) will cover 9500 m<sup>2</sup> and will be completed in April, 1989, at a cost of \$45 million. It will have seven firing chambers (one of which is the catch tank for the 150 mm gun), with varying capacities of up to 10 kg of HE. It will include spaces for HE storage, shot assembly and instrumentation, test cells, control and diagnostic equipment, shops, and laboratories. About 1700 m<sup>2</sup> will be office, drafting, library, data reduction, and conference space. Figure 1 is a floor plan of the facility.

### **GUN SYSTEM**

Initially, we will build a 150-mm-bore, single-stage, propellant-driven gun, capable of firing a 10-kg projectile at up to 2.2 km/s. For future low-velocity experiments, we plan to design a helium breech, using a sleeve valve. For high velocity, we plan to use the breech and 12 m of the 150-mm-diam barrel as the first stage of a two-stage gun. The second stage will have bore diameters ranging from 35 to 100 mm and travel lengths of up to 18 m. For shots up to 2.4 km/s that do not need the full 150-mm diameter, we will substitute a 100-mm single-stage gun with either powder or helium as a propellant. This may either be a new gun or a refitting of our existing 100-mm gun to the rails and tank of the 150-mm system.

Finally, the system can be converted for use on a ballistics range by using the rails to support an evacuated experiment tank of up to 750-mm-diam by 30 m long. Figure 2 is a view of the gun system.

## POWDER BREECH

The breech (Fig. 3) will be made of forged Ni-Cr-Mo steel, fabricated according to ASTM specification A 723. This material has a very high nickel content and therefore can be through-hardened in very thick sections. It is commonly used for large cannons in the United States. Like the tubes, the breech will be heat treated to a yield strength of 965 MPa (140 ksi). In this condition, it will have an elongation of 13% and a reduction of area of 40%. It will be provided with a replaceable liner, which will be heat treated to a yield strength of 1105 MPa (160 ksi).

The propellant charge will be ignited by a 40-mm military primer cartridge firing through a perforated sting. This method will give us close to isochronic ignition. The primer will be fired by a solenoid actuated firing pin, using a dc pulse provided by a charged capacitor.

The breech plug will be composed of two sections to facilitate handling and loading. The main plug, weighing about 210 kg (460 lb), will contain the primer cartridge and a pressure transducer. This portion will be installed and removed by a pneumatically powered fixture that will ride on the rails. The forward section, called the firing plate, contains the sting and powder charge. It will be removed from the plug and taken to the powder room by a rolling cart, similar to a small fork lift. The plug is sealed in the breech by a "hexaseal" modified to include a boss, which will support the outer O ring during installation. Strange and Swift describe operation of this seal.\*

After installation and for our initial series of tests, we will fire the gun with test projectiles and increasingly heavy propellant charges until we reach a peak pressure of 690 MPa (100 ksi), as indicated by quartz pressure transducers. In service, we will limit peak pressure to 550 MPa (80 ksi) to provide a margin of safety. At this pressure, we calculate that a 10 kg projectile will achieve a muzzle velocity of 2.2 km/s, using HPC-95 powder.

## GUN TUBES

Each of the three gun tubes will be 18 m long, made of ASTM A 723 steel, and heat treated to a yield strength of 965 MPa (140 ksi). The three tubes will be connected with massive coupling nuts. The first tube section will have an outside diameter of 457 mm, providing a heavy wall to withstand the high pressures generated at the beginning of the launch. The second tube will have an outside

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\* D. E. Strange and H. F. Swift, *Sealing Ballistic Launchers Against Gas Leakage* (Physics Applications, Inc, 1986), p. 12.

diameter of 355 mm, providing a wall thickness greater than would be needed for a single-stage gun, but which would be needed for future application as a part of the pump tube in a two-stage gun. The third section will have an outside diameter of 254 mm, giving sufficient thickness to provide rigidity for maintaining bore straightness. Bore straightness is extremely important: at a velocity of 2.2 km/s a bore curvature of 42  $\mu\text{m}$  per metre will produce a lateral accelerating force of 500 g on the delicate projectile.

To measure bore straightness, we will use three methods. In the first, a bridge with a sensor at the center, as described in Appendix A, will measure straightness of a short section directly, assuming that the diameter is constant over the length of the gage.

In a second method, we will use a precision spindle on which is mounted a gagehead, as shown in Fig. 4. The spindle centerline is adjusted to coincide with the bore, and the gage measures diameter and roundness as the spindle is rotated. This fixture will also measure alignment of two tubes at a coupling by taking a measurement on each side of the dividing line, with the support buttons resting on the same section for both measurements.

The third method we will employ uses an autocollimator and a mirror mounted on a sled that moves along the bore. A microprocessor coupled to the autocollimator analyzes the data as it is taken.

Ports will be machined into the tubes at various locations to accept piezoelectric pressure transducers. Using high speed recordings, we will be able to measure pressures vs time to validate our internal ballistics codes.

The tube joints will be sealed with a combination metal and O ring seal, known as a diamond seal (Fig. 5). This design, used in a number of installations, has been shown to reliably seal at pressures to 345 MPa (50,000 psi) and at vacuum levels to 0.13 Pa ( $10^{-3}$  Torr). The joints will be aligned by step joints having interference fits (Fig. 6). The outer portion of the step will be thin enough to deform elastically during assembly, thus limiting the bearing forces between the two components and thereby minimizing the possibility of galling. Our analysis shows that a diametrical interference of 0.05 to 0.25 mm (0.002 to 0.010 in.) will result in reliable alignment without producing excessive bearing forces.

## COUPLING NUTS

Barrel sections will be coupled using massive coupling nuts with right- and left-handed threads (Fig. 6). The nuts will be rotated by a fixture having two hydraulic motors with gear reducers, each capable of producing 40,000 nm (350,000 lb-in) of torque on the coupling nut. This will result in an axial preload of 72,000 kgf (160,000 lb), sufficient to withstand an internal static pressure of 28 MPa (4,000 psi) without separating the contact faces.

At static pressures above 28 MPa, separation will be minimal, as the nuts are extremely rigid. Under transient pressure conditions, separation is not expected to be a significant problem, due to the great axial stiffness of the coupling nuts. We are conducting a mathematical analysis to predict the separation amount.

Right- and left-handed (R & L) threads were selected over differential threads for a number of reasons. First of all, the linear travel of a basic differential thread of this size is extremely long. In smaller systems, the travel can be reduced by means of a nut-and-collar system, but the overall size grows rapidly with scale. Second, the gun may be fired many times before uncoupling. Over a period of time, lubricants are extruded and friction increases, making it difficult to break loose a joint. Loosening torque with R & L threads will be only 69% of that required for tightening (with constant friction coefficients). Finally, the torque required to produce a given axial force is only about 13% greater for R & L threads than it is for differential threads.

## RAIL AND SUPPORTS

A primary objective of the design is to allow users to change launch tube length so as to convert the gun to either a 100-mm single-stage, or to a 150/100-mm or 150/75-mm two-stage, to install a ballistics range, or to provide for unforeseen future configurations. To provide such flexibility, our design calls for a pair of precision rails upon which all components will rest. Each component will have its own set of support carriages, which will be adjusted so that when the component is placed on the rails it will automatically be aligned to the target chamber (see Figs. 7 and 8). Further, the design allows any component to occupy any axial position along the rails, allowing changes in tube lengths and, incidentally, allowing us to move the 150-mm gun back onto the rear rails for storage while using the 100-mm system on the front section.

The rails have a diameter of 50.8 mm, are mounted on steel extrusions, and are further supported by massive I-beams. The bearings will be "Roundway" rollers, capable of supporting 5600 kg (12,300 lb.) per bearing.

The beams will be installed first and rough aligned. Next, the LLNL Precision Systems Development Group will install and precision align the rail/support assemblies. The space between the rails and the beams will then be filled with an epoxy grout to provide firm, continuous support. Any future adjustments required due to settling of the foundation will be made by using the adjustable supports under the beams.

While the front 19 m of the rails will be rigidly supported and precisely aligned to the target chamber, the rear 23 m will be mounted on lateral rails so that it can be moved 762 mm to the side. A side-mounted hone will then be automatically aligned to the launch tube. This feature will be most useful when the two-stage configuration is implemented because it will allow us to clean and hone the

launch tube. During single-stage operation, the side-mounted honing bench will be used as a swab to clean the barrel after each shot.

## EXPERIMENTAL VESSEL

Our experimental vessel (Fig. 9) will be made of type 304L stainless steel and will be 3.8 m in diameter, 12.5 m long, and 89 mm thick. The vessel has been designed to safely contain the energy released from detonating up to 10 kg of high explosives. The experiment will be located 2.78 m from the gun port into the tank to provide a reasonable wall standoff from the explosive sample. Both the gun tube and the target support will be decoupled from the vessel structure to avoid disruption of critical alignments due to vessel closure and vacuum pumpdown. The soft-mounted vessel will essentially float about the gun and target. The target support will be mounted directly to the concrete foundation with the gun port sealed by bellows. The rear half of the tank, mounted on rails, can be moved when we need access to the vessel interior, which will be necessary when experiments are mounted. The joint between halves is secured by a large ring, similar to the type used on autoclaves. Hydraulic cylinders will rotate the ring, which will provide a rapidly operating, rigid joint that can withstand pressures ranging from vacuum to blast conditions. Inside the tank will be a permanent floor, and when the joint is separated a pair of ramps will be lowered to allow traffic, including fork lifts, to enter the tank.

Inside the tank will be a projectile catcher, supported by an overhead rail, containing a series of steel plates to stop the projectile.

Before firing, the portion of the tank containing the experiment may be evacuated to 0.13 Pa ( $10^{-3}$  Torr) to satisfy the requirements of the experiment. Containment calculations, however, were conservatively based on an initial pressure of 1 atm. After firing and before the tank is opened, it will be purged with ventilating fans to expel propellant smoke and HE products.

Since the location of the experiment will be 2.78 m from the gun port into the vessel, the muzzle section of the gun must extend about 3.5 m beyond the final support. If left unsupported, the muzzle will sag about 0.1 mm (0.004 in.). We have provided a hydraulically powered roller support to counteract this sag. We chose a spring support over a fixed support because target alignment is done at atmospheric pressure, and a tank-mounted rigid support could move during vacuum pumpdown.

Another potential source of misalignment results when the tank moves during pumpdown, at the point where the muzzle enters through the vacuum seal. To avoid this problem, we provided a floating O ring seal, mounted on a bellows, which will allow lateral tank motion without muzzle movement. To protect the bellows from blast pressure, we included a labyrinth, which will restrict pressure buildup within the bellows.

## **SERVICE, OPERATION, AND MAINTENANCE**

Gun components will be much too massive to be handled manually. The breech plug, for example, will weigh almost 230 kg (500 lb). We are designing a plug installation fixture that will ride on the main rails (Fig. 10). A rotating flange will be connected to the plug, and a pneumatic motor will rotate the plug to remove or install the fixture. After removal, the fixture will be rolled backward on the rails until it is well away from the breech. A portable fixture will be attached to the firing plate, which will then be disconnected from the plug. The firing plate will be taken to the powder loading room, where it will be rotated to a vertical position for loading the powder. During installation, we will reverse the procedure.

To install the projectile and its retainer, we will attach a fixture to the breech plug, which will support first the projectile and then the retainer. A pneumatic motor will provide power to both tighten and loosen the retainer.

After each shot, the bore must be thoroughly cleaned. We are providing a powered cleaning assembly, which will also hone the bores when necessary. The shaft will be rotated with a 3-kW variable-speed electric motor drive, while the stroking will be done by a reversible hydraulic motor. Rotation speed will be continuously variable from 50 to 400 rpm, and stroking speed will vary from 8 m/min (25 ft/min) to 30 m/min (100 ft/min).

The coupling nuts, weighing from 550 to 1000 kg, will be moved into position on a cradle supported by the bridge crane. After starting the first thread by hand, the operator will use a hydraulically powered driver (Fig. 11) to tighten the nuts. The driver contains two motors with gear reducers, which can be operated in series for maximum speed or in parallel for maximum torque. The fixture will be mounted on pedestals of differing heights to allow one driver to be used for both the 711-mm (28-in.) gear of the breech nut and the 610-mm (24-in.) gears of the barrel nuts. The pedestals may remain in place on the gun tubes.

Because our gun will move much greater distances along its rails than would conventionally designed guns, we cannot use conventional hydraulic cylinders. We have designed a traction drive with a pneumatic motor to drive steel rollers that grip the hardened rails (Fig. 12). The force required to move the entire 1.8 tonne (40,000 lb) gun is about 100 kg, exclusive of O ring drag force. We have designed the linear drive to produce about 500 kg of thrust.

## **BARREL VENTING EXPERIMENT**

Since many of our targets will be high explosives, which may detonate on impact, the muzzle must be separated from the target by distances on the order of 1 m. A projectile in free flight over this

distance will experience some tilt, which will severely degrade the diagnostics if the amount is greater than a few milliradians.

It has been proposed that a major source of the tilt is residual pressure present behind the projectile as it leaves the muzzle. Our calculations indicate that at maximum velocity, the exit pressure is about 17 MPa (2500 psi), which could exert considerable tumbling force on the base of the projectile. We considered the possibility of venting the excess gases near the muzzle to reduce this pressure, and we performed calculations to predict muzzle pressure reduction vs amount of venting. Optimum pressure reduction was obtained by venting about 50% of the barrel area over a distance of about 0.5 m.

Recently, we conducted a series of experiments using our 100 mm gun to determine the effectiveness of venting to reduce tilt. A 1-m barrel extension was attached to the muzzle of the existing gun, and a target was set up to provide 1.2 m of free flight. An array of piezoelectric pins around the perimeter of the target measured tilt and velocity. For the initial part of the series, the projectiles were standard, short-spool types having a length-to-diameter ratio of 0.7; the projectiles were equipped with copper impactors to provide a constant mass of 1.0 kg. Shots were fired with velocities of 0.8, 1.2, and 2.0 km/s in an unvented barrel to provide baseline data. A series of holes was then drilled in the extension (their area representing 40% of the bore area over a distance of 0.56 m), and the series was repeated.

The first unvented series produced tilts of from 6 to 17 mrad; the tilts tended to be greater at high velocity. Vent holes drilled into the barrel reduced muzzle pressure by a moderate amount at low velocity and up to 60% at high velocity. Tilt at low velocity was not improved by the venting, but at 2.0 km/s it was reduced from 12 mrad to 3.6 mrad.

We then made four more shots, using projectiles with a length-to-diameter ratio of 1.7. These shots showed much-reduced tilts compared with shots conducted with short projectiles. Further, the tilts decreased with increasing velocity, to about 4 mrad at 1.56 km/s.

Our interpretation of the results is that reduction of tilt at all velocities is principally achieved by increasing projectile length, a result that would be predicted by basic principles. Stability could undoubtedly be enhanced by concentrating the mass at both ends of the projectile, to increase its moment of inertia.

Venting is effective only at high velocity, particularly when short projectiles are used. Indeed, when striving to increase velocity, an excellent way to reduce projectile mass is to shorten the body, and this is where venting will be most effective. The 150-mm muzzle design provides for a future extension.

## STRESS ANALYSES OF BREECH AND BREECH PLUG

We have used the LLNL computer code NIKE2D—an implicit, two-dimensional finite-element code—to analyze the breech design. The first loading we examined was from a brief pressure pulse with a peak pressure of 690 MPa (100 ksi) traveling through the breech. Results indicate that this loading will cause small amounts of yielding at the inner surface. We show in Fig. 13 the contours of peak effective stress through the breech resulting from the passage of the pressure pulse. Two cases were considered: The breech with wear insert in place, and the breech alone. The latter case models a condition where the wear insert is cracked and does not contribute structurally. Figure 14 shows effective strain contours. We conducted a similar analysis in which we used a pulse with a peak pressure of 2760 MPa (four times design pressure). Plots of peak effective stress and effective plastic strain are shown in Fig. 15. These results suggest that the breech could withstand this loading.

We will statically pressurize the breech during its manufacture to produce autofrettaging effects. When manufacture is complete, the breech assembly will be pressurized to 690 MPa so that we may proof test the seals and coupling nut. An analysis of the breech plug design suggests that the inner surface of the breech and the first thread in the plug will yield at about 550 MPa (80 ksi). At 690 MPa, yielding will have taken place in the first three threads of the plug. Figures 16 and 17 are contour plots of effective stress in the breech plug and the breech, respectively. Figures 18 and 19 are contour plots of effective plastic strain in the plug and breech, respectively.

## FUTURE CAPABILITIES

The range of reproducible velocities achievable with a powder breech is about 0.8 to 2.2 km/s with a 10-kg projectile. If, in the future, researchers wish to conduct experiments in the range of 0.1 km/s, we will add a gas breech with a sleeve valve and helium as the driving medium. To reach higher velocity—to about 6 km/s—we will convert to a two-stage configuration, with a range of launch tubes.

For experiments that do not require the full 150-mm capability, we will mount our existing 100-mm gun on the rails; we expect the necessary conversion to take 4 h or less.

Another application will be to fire small arms along a ballistic range into the target chamber. In the simplest form, the range will consist of a 30-cm-diam tube that will be up to 40 m long. For complete instrumentation, the range could be increased to 1-m diam, with as many instrumentation stations as may be needed.

Until expansion is needed, we are confident that experimenters will keep the 150-m, single-stage gun with powder breech busy for the foreseeable future.

## FIGURE CAPTIONS:

Figure 1. Floor plan of the High Explosive Application Facility at Lawrence Livermore National Laboratory.

Figure 2. Overall view of gun system.

Figure 3. Schematic of powder breech. The propellant charge will be ignited by the 40-mm primer cartridge at left. The projectile is initially located at the left end of the replaceable sleeve.

Figure 4. Gagehead mounted on precision spindle. The gagehead is one of three methods we will use to measure bore straightness. The spindle centerline, is adjusted to coincide with the bore, and the gage measures diameter and roundness as the spindle is rotated.

Figure 5. End joint seals for HEAF 150-mm gun. The diamond seal is a combination metal and O ring seal, which will be used to seal the three tube joints.

Figure 6. Joints between gun sections. (a) Diamond seal between barrel sections 1 and 2. (b) Diamond seal between barrel sections 2 and 3. Both barrel sections will be coupled with massive coupling nuts.

Figure 7. Detail of barrel section 1 (view toward tank) showing support carriages and precision rails, upon which all components will rest. Each component will have its own set of support carriages, which will be adjusted so that when the component is placed on the rails it will automatically be aligned to the target chamber.

Figure 8. Schematic views of locking clamp and traverse drive. (a) Overview. (b) Detail showing location of air cylinder and seismic clamps.

Figure 9. Schematic of experimental vessel. The vessel, which can be evacuated to 0.13 Pa, will safely contain the energy released from the detonation of up to 10 kg of high explosives.

Figure 10. Breech plug and installation fixture. Because it weighs almost 230 kg, an installation fixture will be necessary. The installation fixture will ride on the main rails.

Figure 11. Hydraulically powered driver for tightening the coupling nuts. The two motors can be used either in series for maximum speed or in parallel for maximum torque. One driver can be used for both the breech nuts and the barrel nuts.

Figure 12. Traction drive, to be used to move the gun along its rails. The drive will have a pneumatic motor to drive steel rollers that grip the hardened rails.

Figure 13. NIKE2D calculations of contours of effective stress for the peak load of the breech, both with and without the wear insert.

Figure 14. NIKE2D calculations of small plastic strains on the breech, both with and without the wear insert.

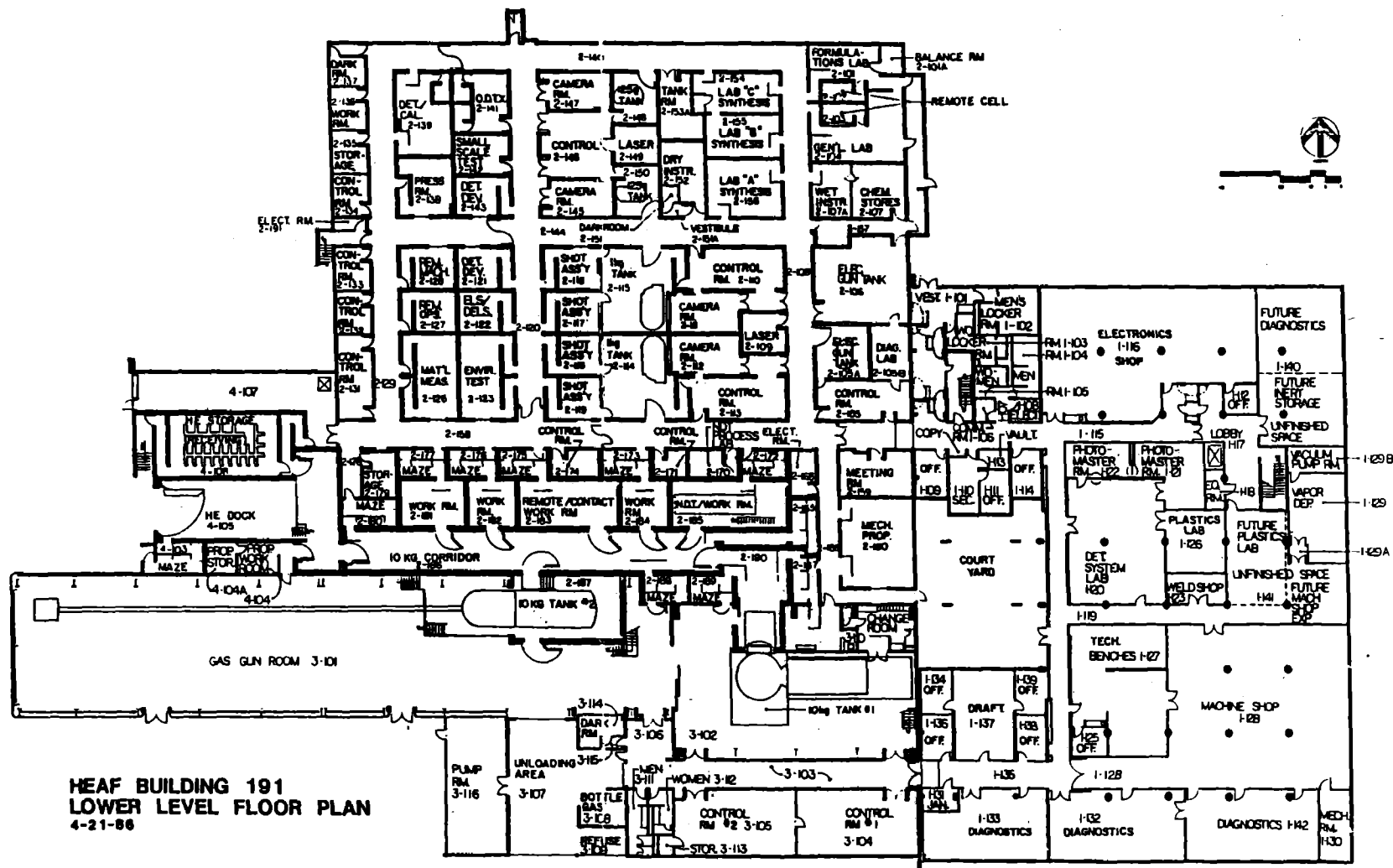
Figure 15. NIKE2D calculations of peak stresses and resultant plastic strains for a worst-case prediction of four times the design pressure. The breech would deform but would not fail catastrophically.

Figure 16. Contours of effective stress of the breech plug at an internal pressure of 690 MPa (100 ksi). Peak stress of 945 MPa (137 ksi) in the first thread is reduced to an average effective level of about 200 MPa (30 ksi) in the remainder of the threads.

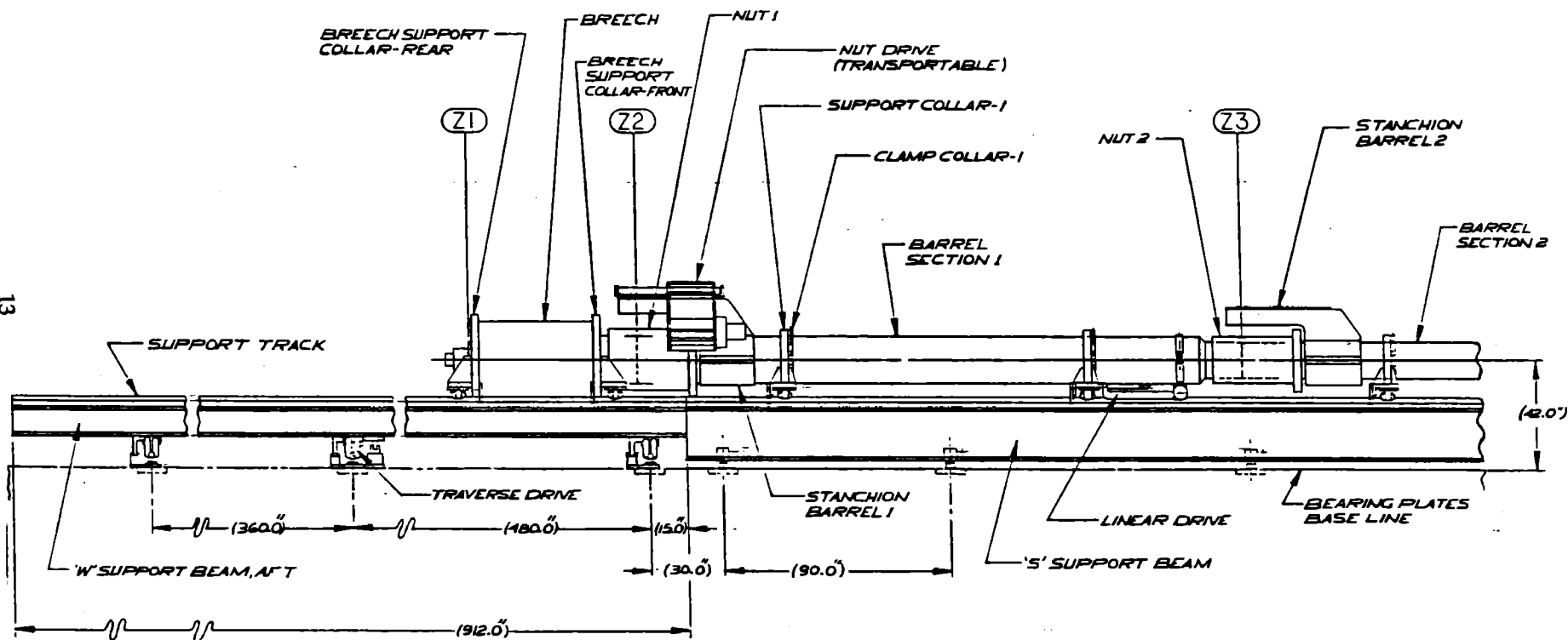
Figure 17. Contours of effective stress of the breech at an internal pressure of 690 MPa (100 ksi). Peak stress of 973 MPa (137 ksi) in the first thread is reduced to an average effective level of about 200 MPa (30 ksi) in the remainder of the threads.

Figure 18. Contours of effective plastic strain of the breech plug at an internal pressure of 690 MPa (100 ksi). This analysis shows that there is a small plastic strain on the first thread.

Figure 19. Contours of effective plastic strain of the breech at an internal pressure of 690 MPa (100 ksi). This analysis shows that there is a small plastic strain on the first thread.



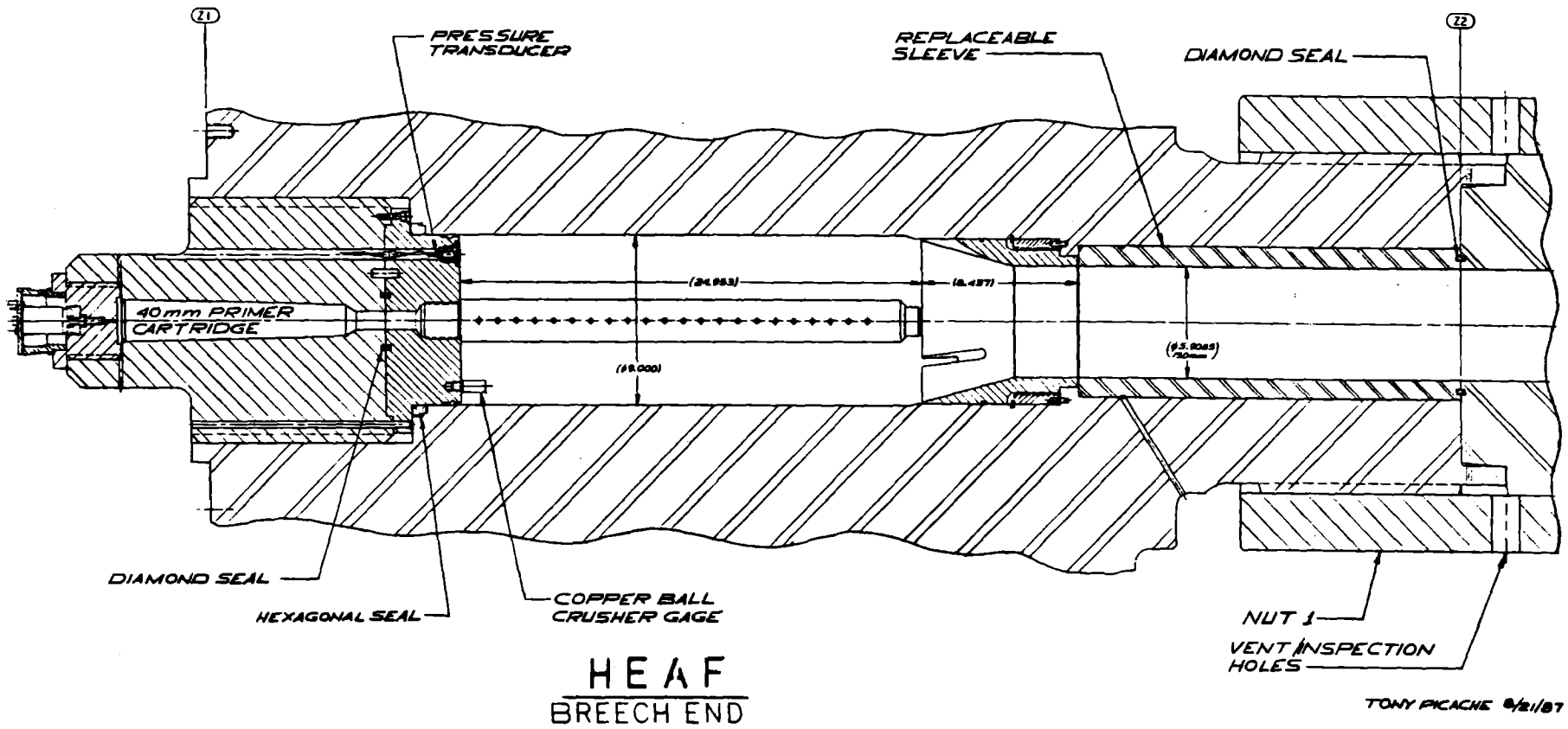
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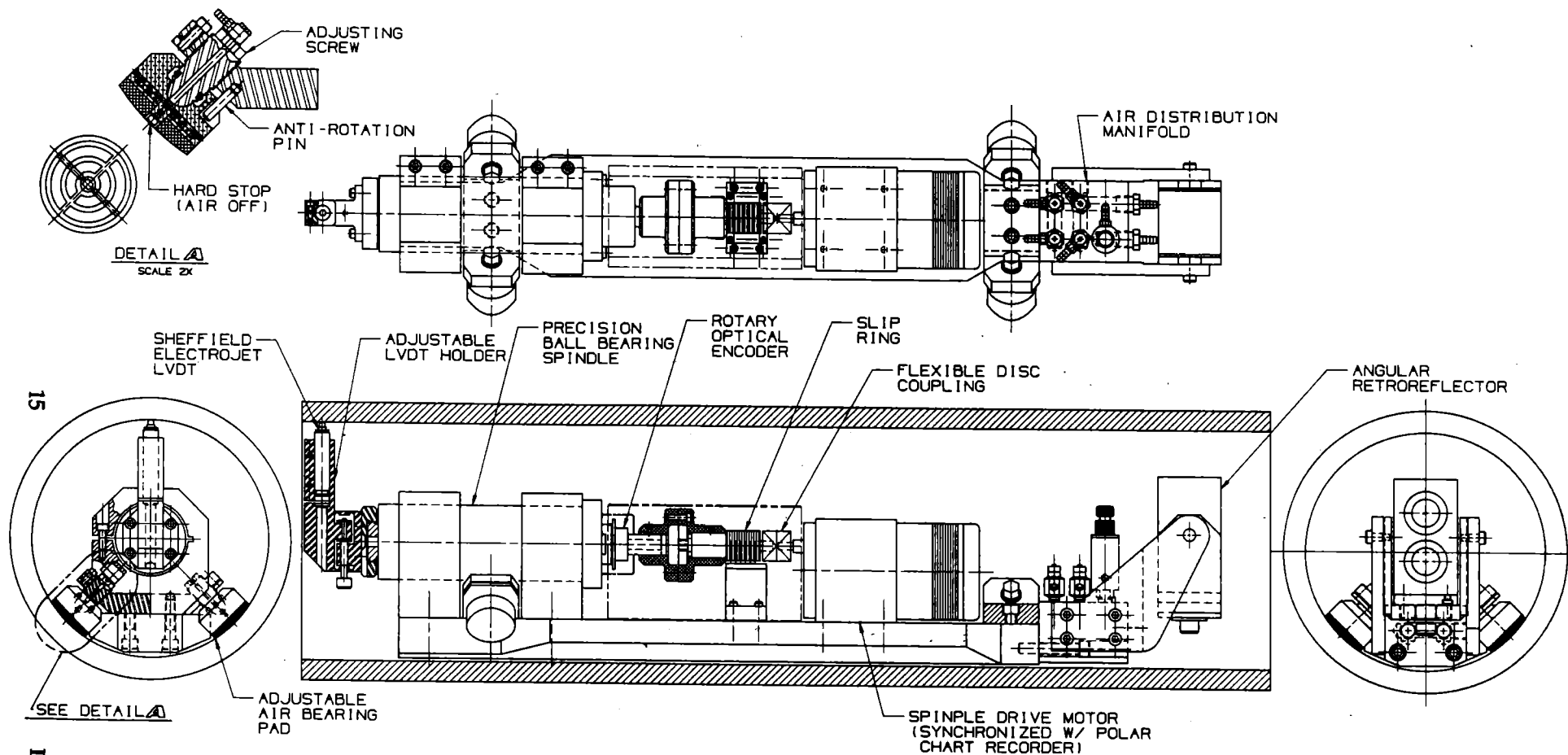


SIDE ELEVATION VIEW

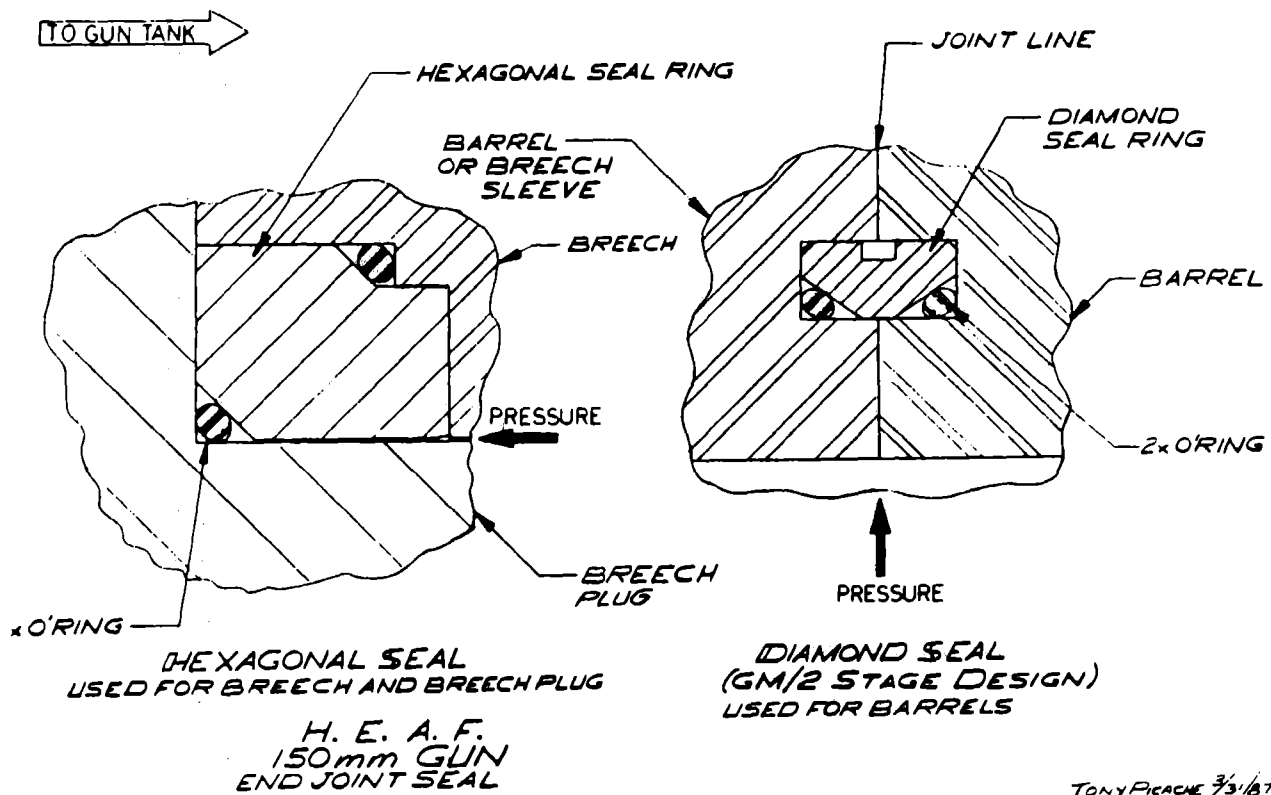
H.E.A.F.  
150mm GUN  
ASSEMBLY

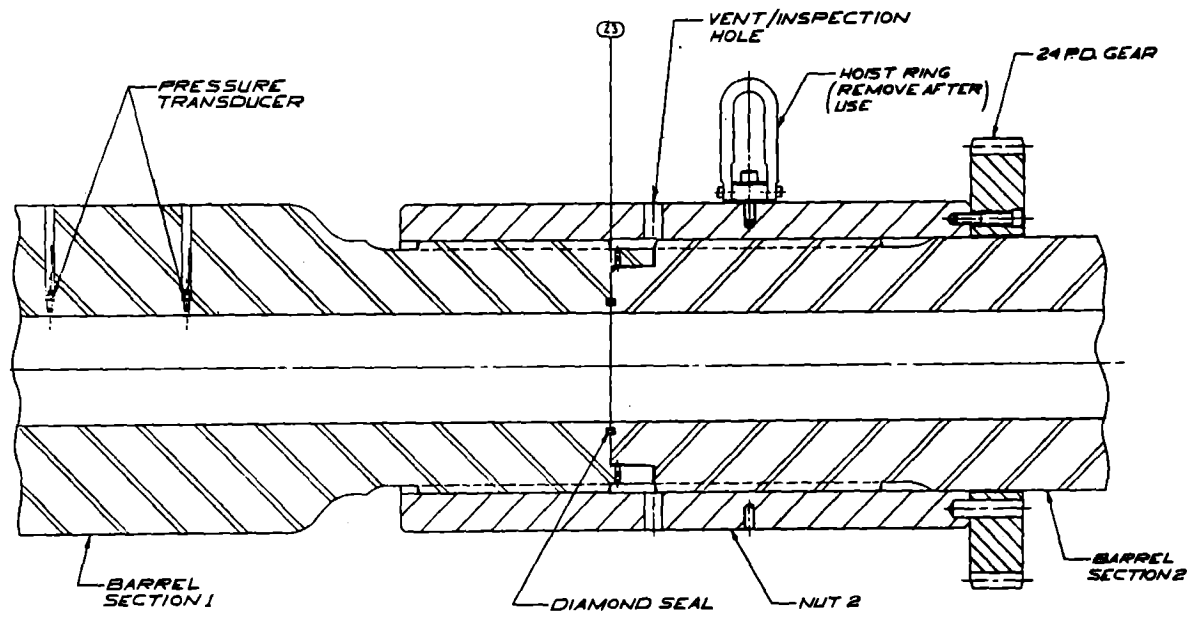
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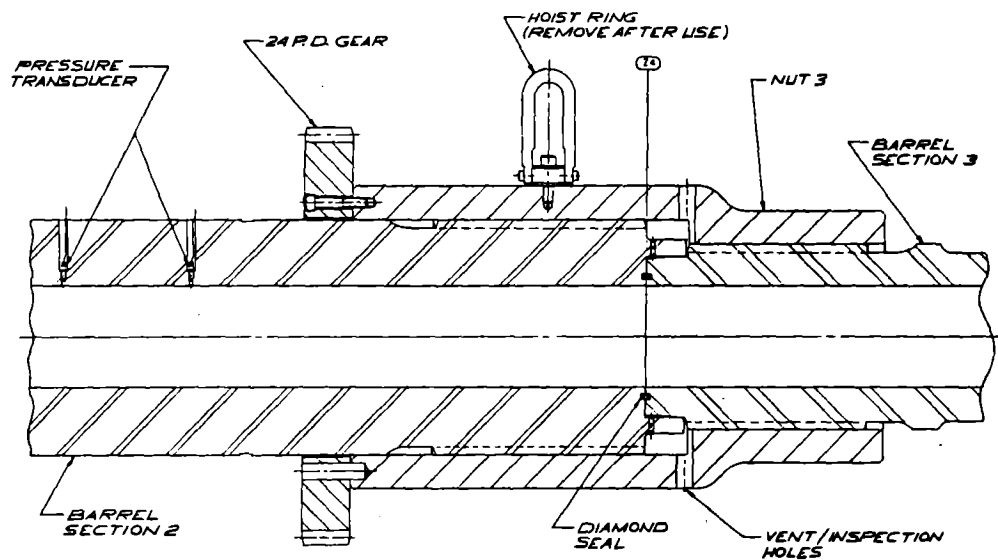


INSPECTION GAGE - 150MM (5.9055) BARREL

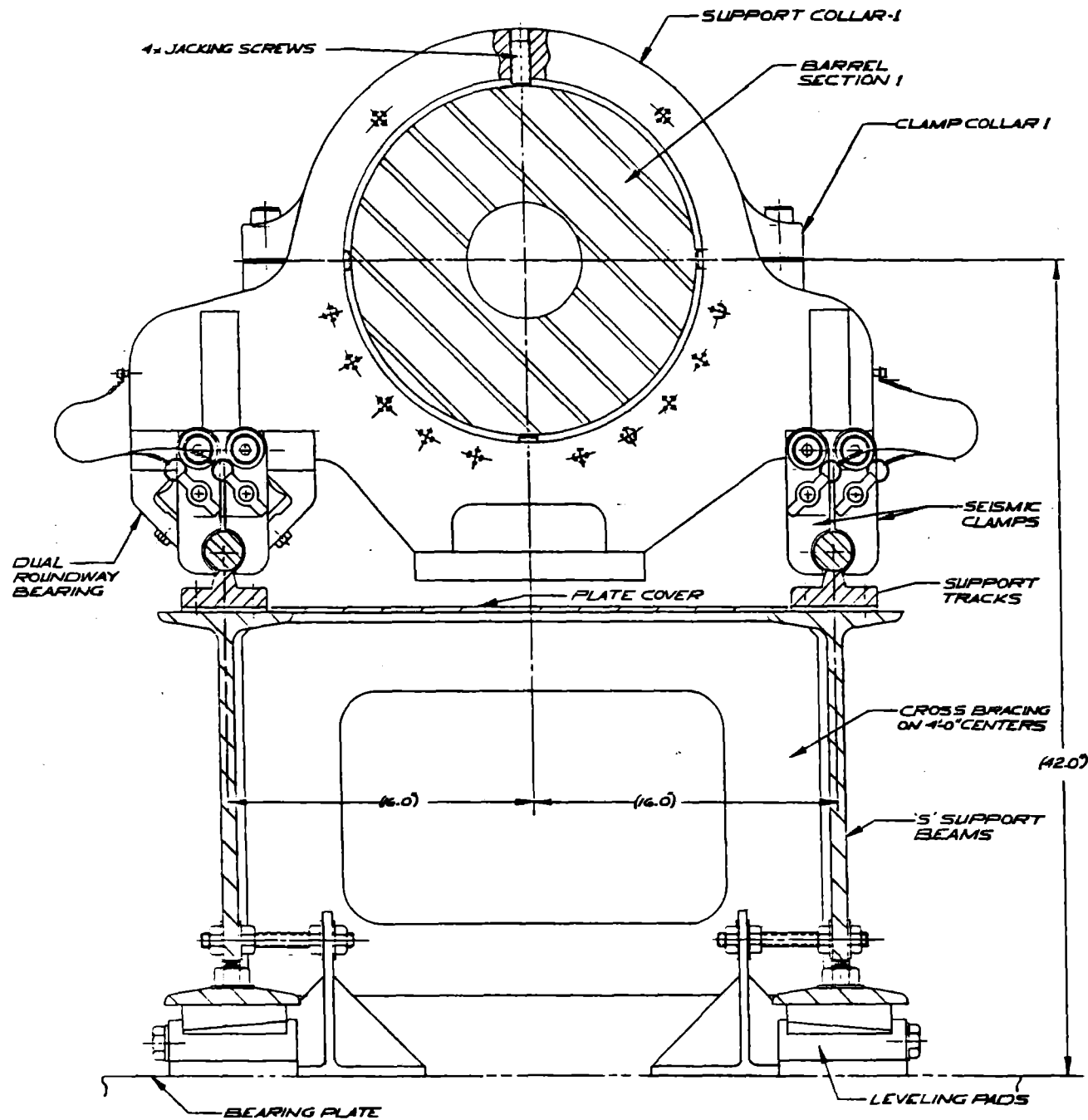




HEAF  
NUT 2 SECTION



HEAF  
NUT 3 SECTION

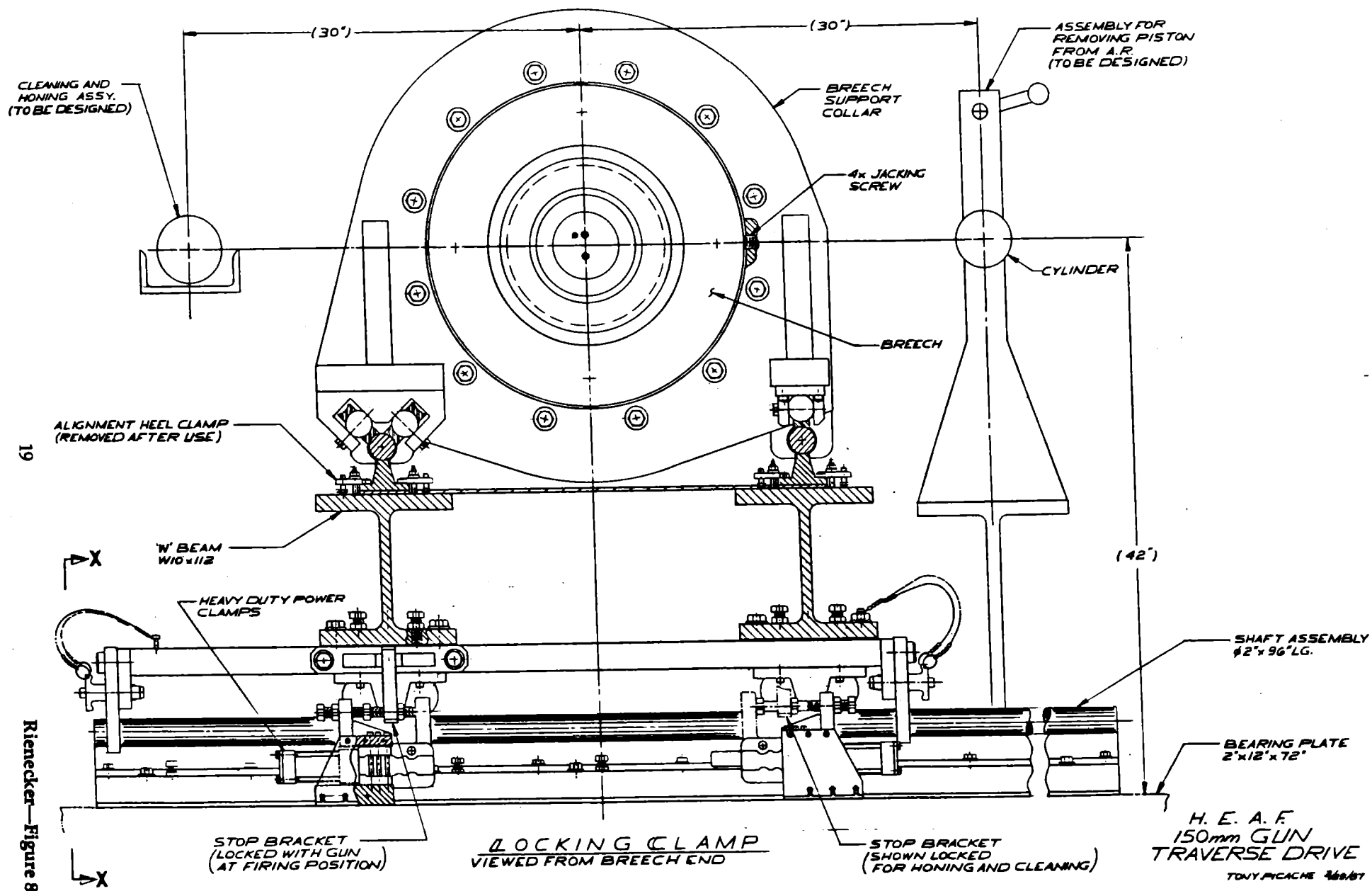


SECTION VIEW-BARREL 1  
VIEW LOOKING TOWARD TANK

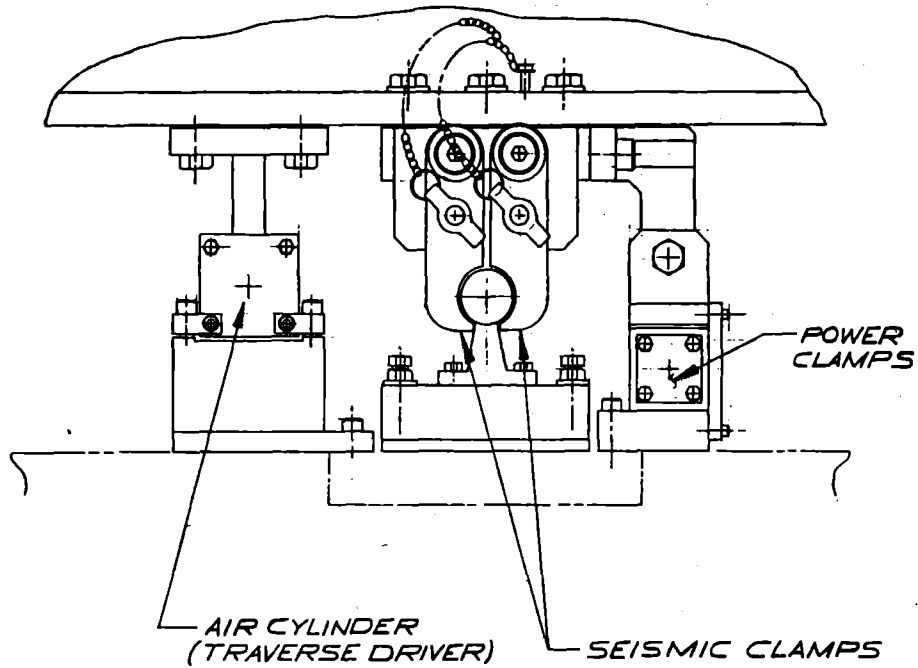
H. E. A. F.  
150mm GUN  
SECTION-BARREL 1

Tony P. LARNE 8/24/61

(a)



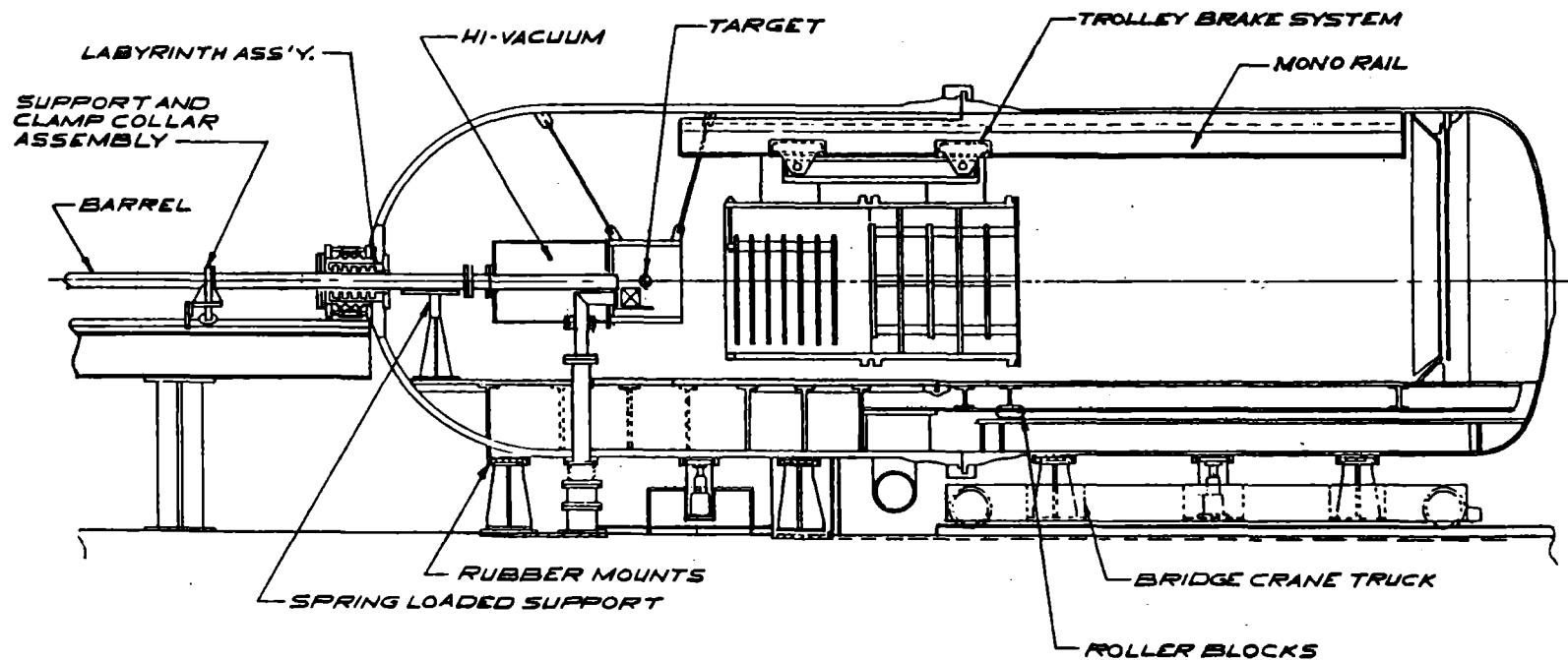
(b)



VIEW X-X

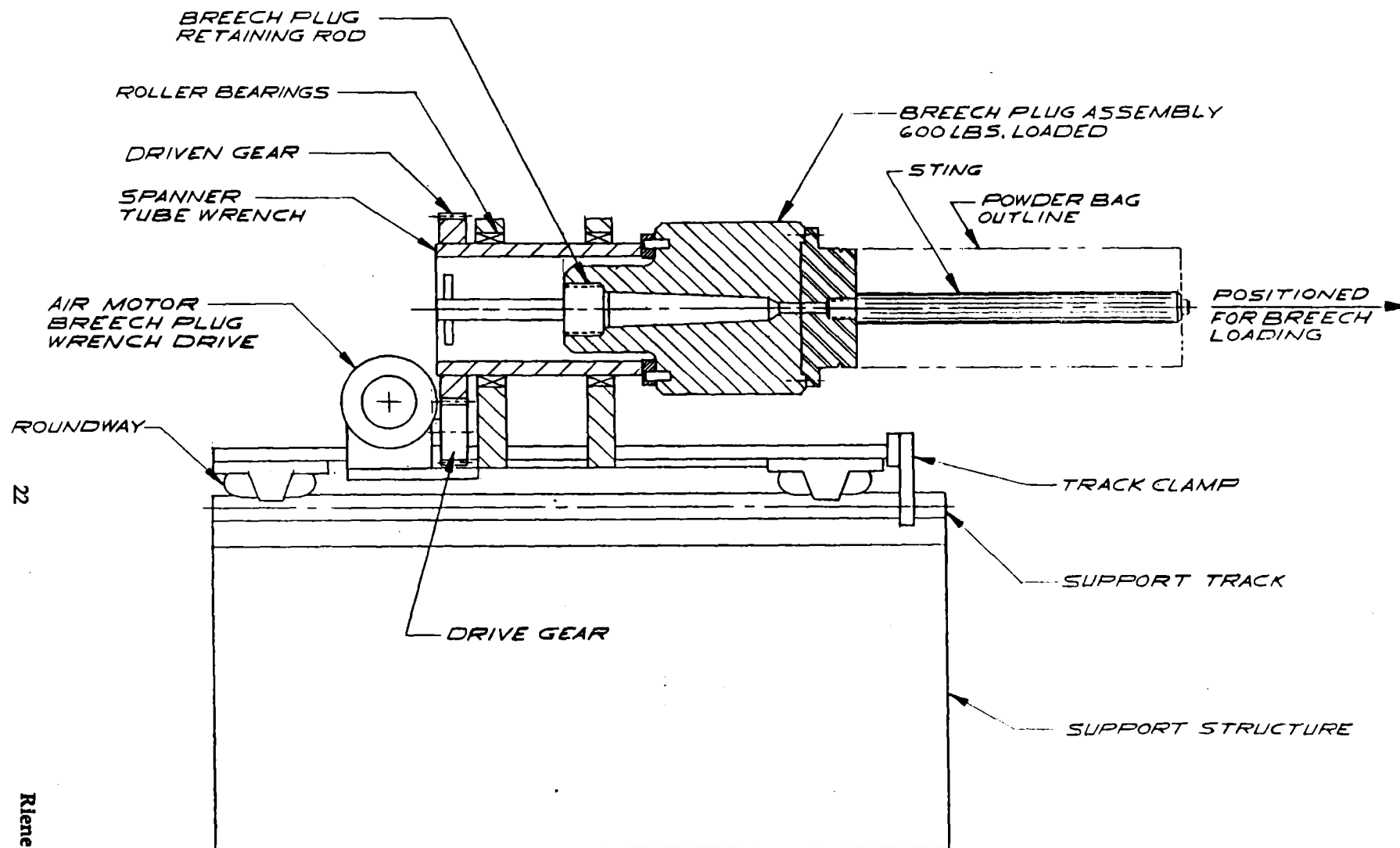
H. E. A. F.  
150mm GUN  
TRAVERSE DRIVE

TONY PICACHE 3/30/87



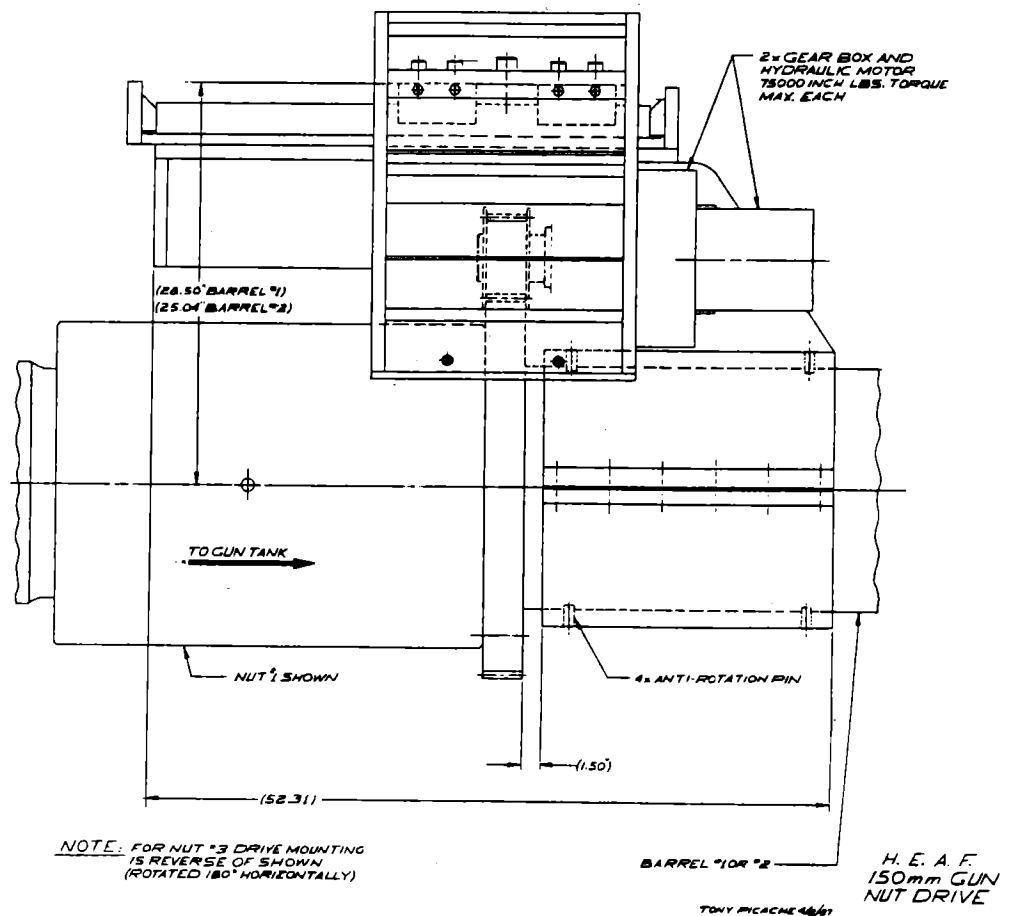
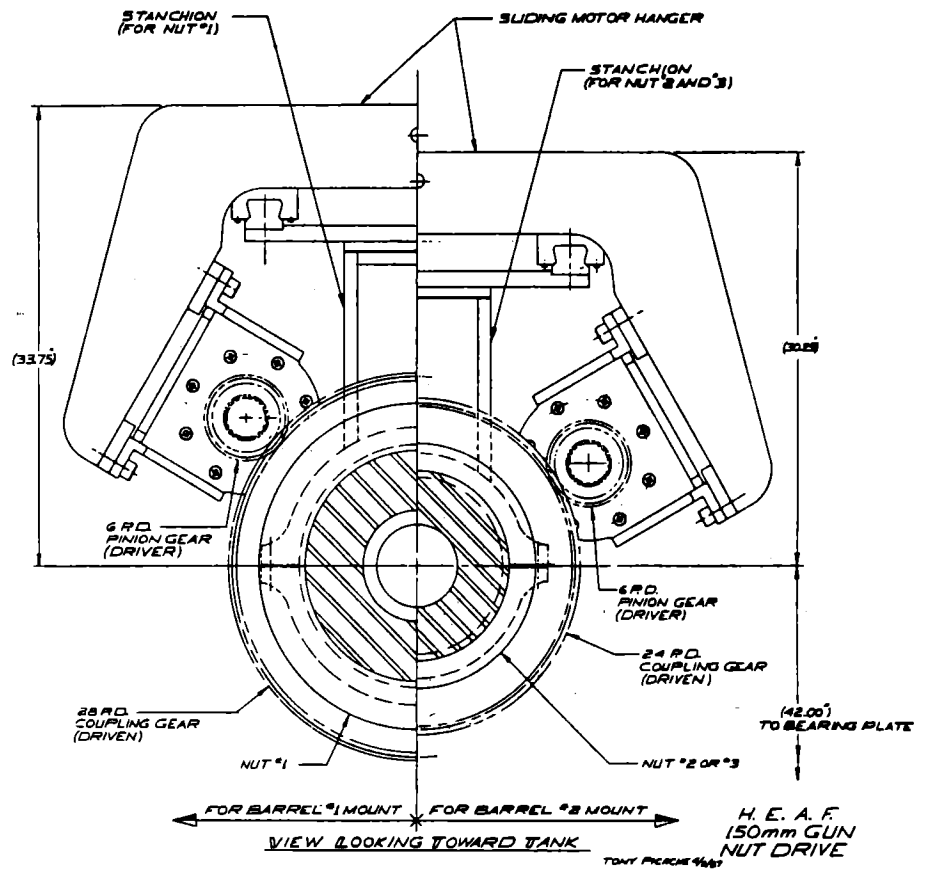
**HEAF**  
 TARGET TANK (10KG)

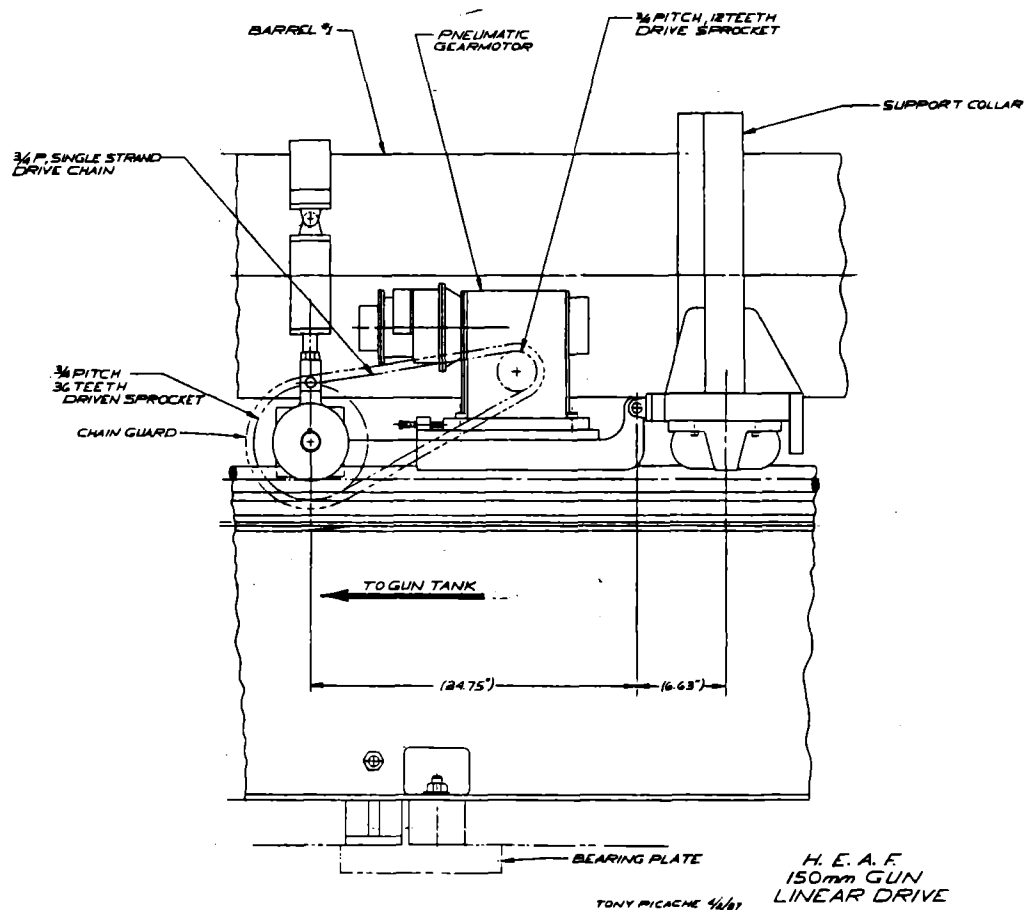
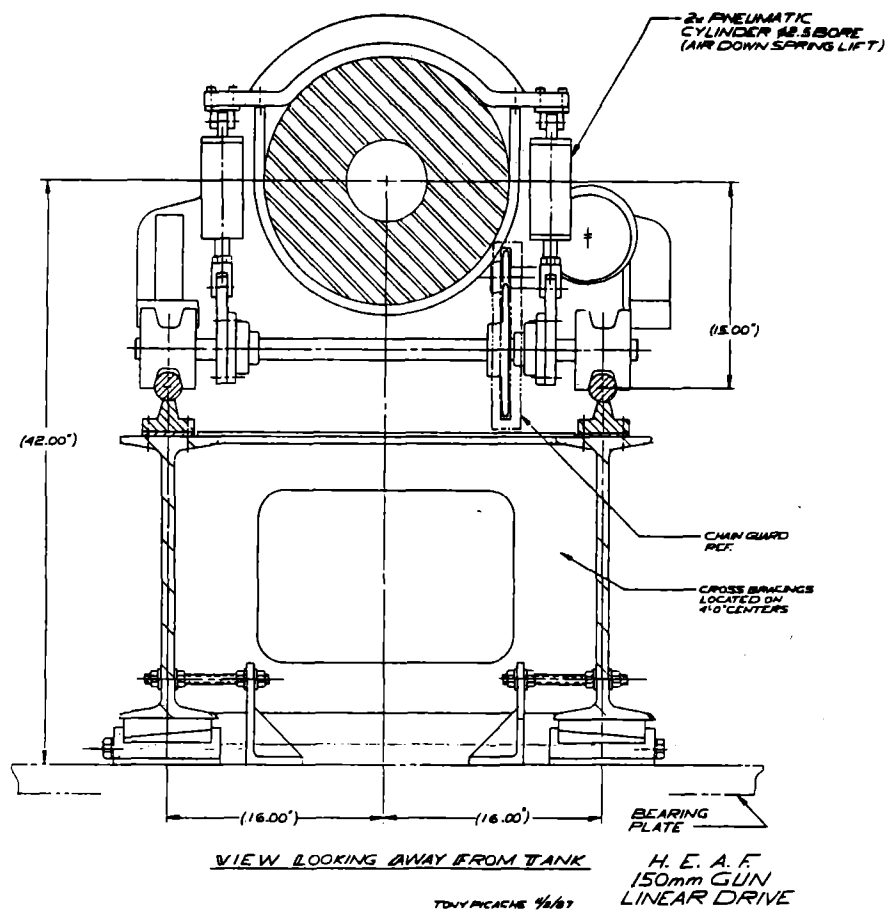
TONYPICACHE 9/8/67



H. E. A. F.  
150mm GUN  
BREECH PLUG/LOADING OR UNLOADING TABLE

TONY PIERCE 4/17/87

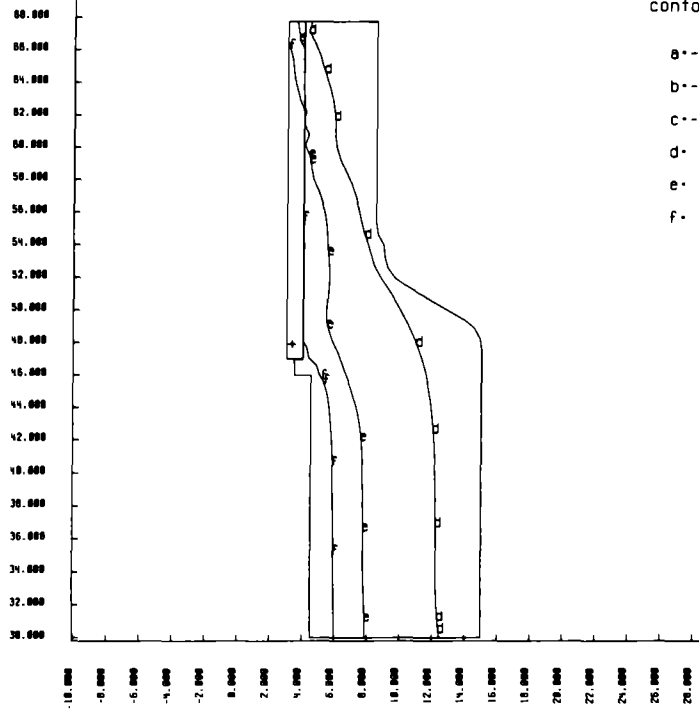




heaf breach - #4 slide line - 9-4-20 insert - damped, slipf - 2.0  
time - 2.00000e-03 contours of effective stress  
dsf - 1.00000e+00



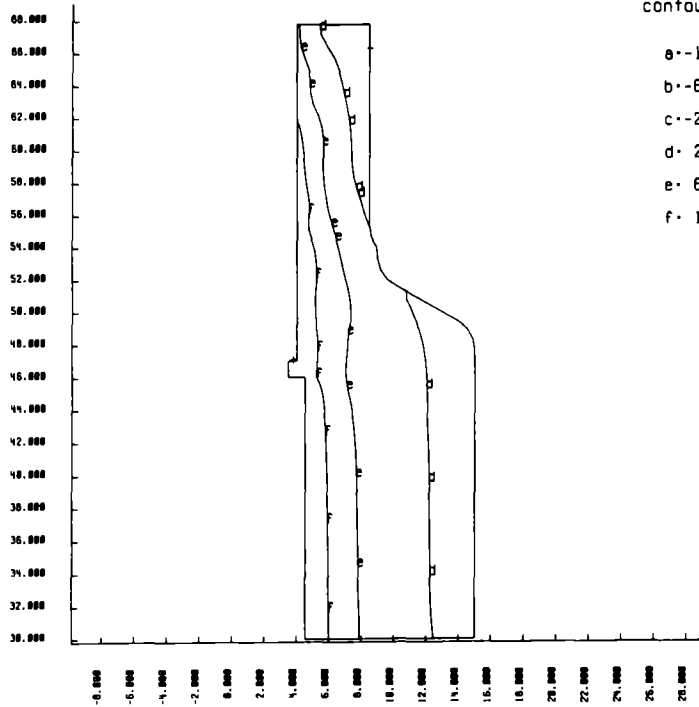
min(-) - 1.98e+03  
max(+) - 1.80e+05  
contour levels



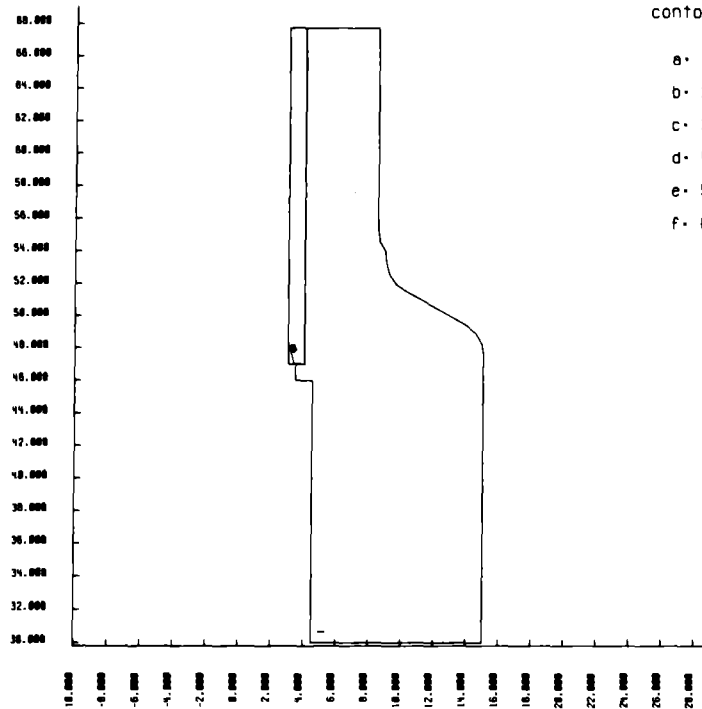
heaf breach - pressure pulse - rc40 breach - damped  
time - 2.00000e-03 contours of effective stress  
dsf - 1.00000e+00



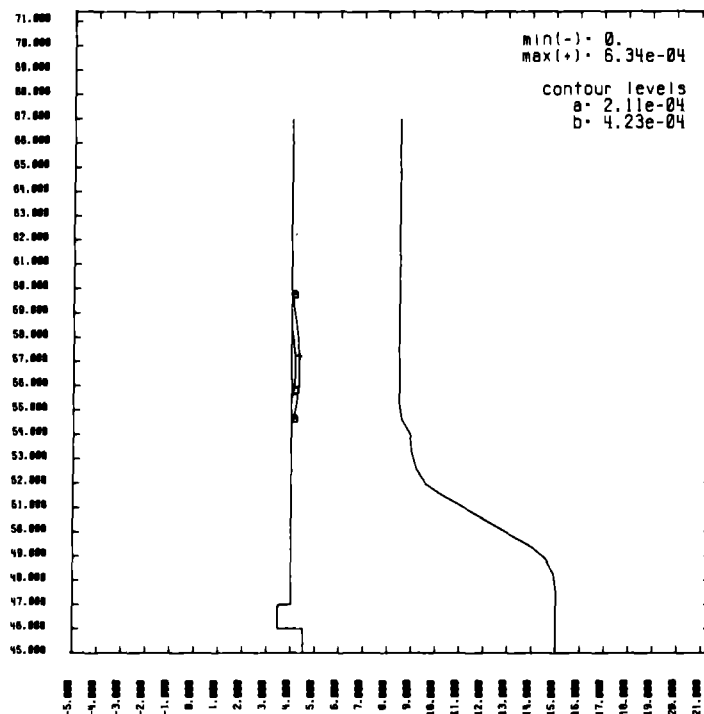
min(-) - 4.62e+03  
max(+) - 1.78e+05  
contour levels



heaf breech - #4 slide line - 9-4-20 insert - damped, slpf = 2.0  
time = 1.50000e-02 contours of effective plastic strain  
dsf = 1.00000e+00 min(-) = 0.  
max(+) = 1.68e-03  
contour levels

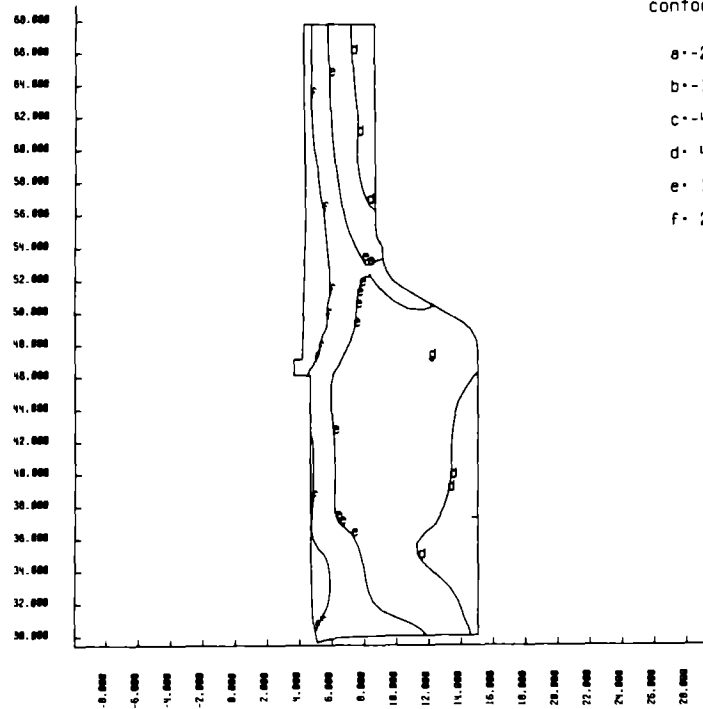


heaf breech - pressure pulse - rc40 breech - damped  
time = 0.  
dsf = 1.00000e+00 contours of effective plastic strain



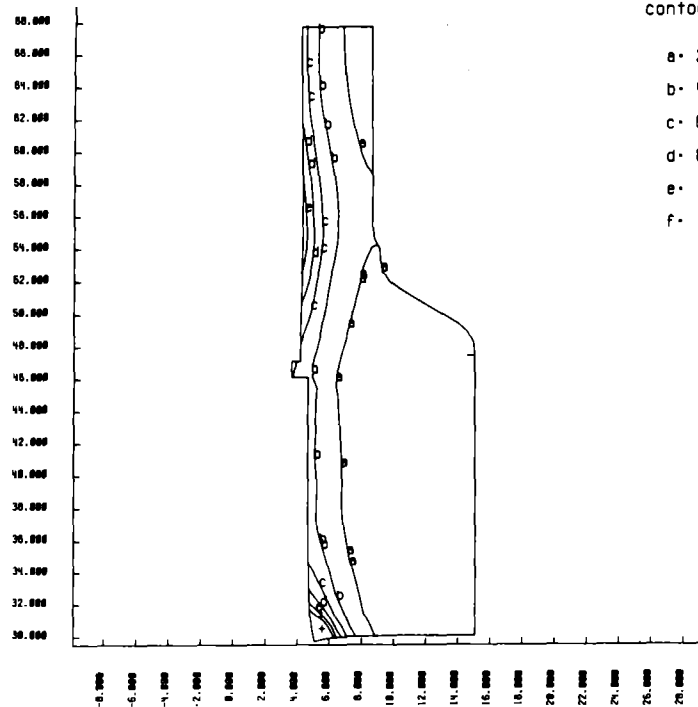
heaf brech - 4x pressure pulse - rc40 brech - damped  
time - 6.00000e-03 contours of effective stress  
dsf - 1.00000e+00

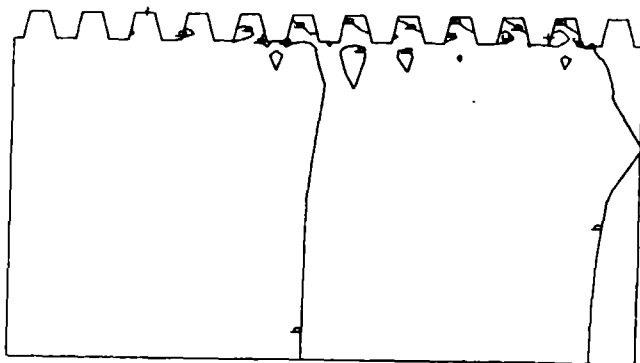
min(-) = 7.81e+02  
max(+) = 2.25e+05  
contour levels



heaf brech - 4x pressure pulse - rc40 brech - damped  
time - 1.50000e-02 contours of effective plastic strain  
dsf - 1.00000e+00

min(-) = 5.74e-04  
max(+) = 2.80e-01  
contour levels





Rienecker—Figure 16

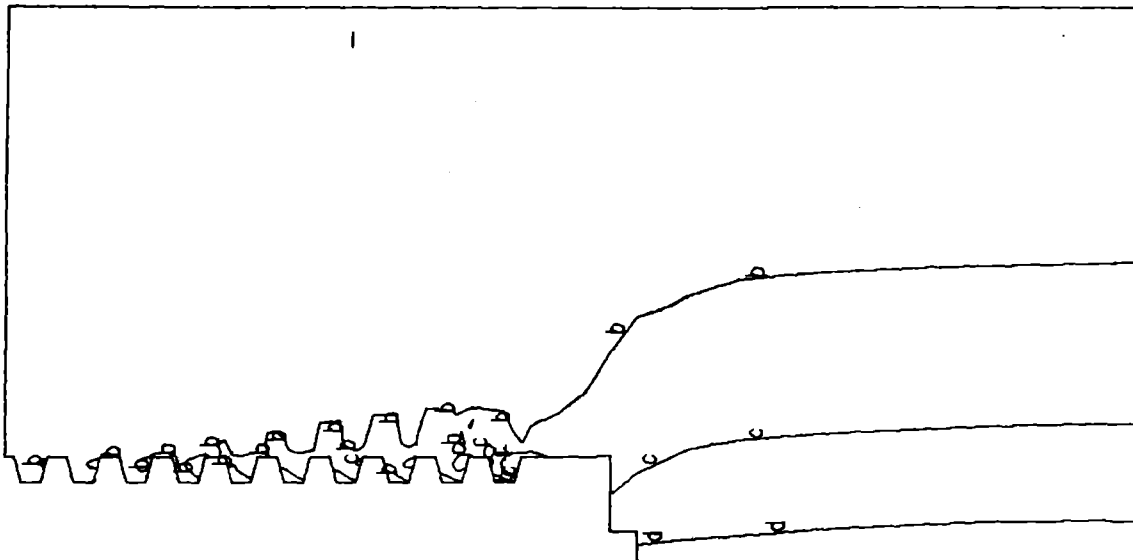
Contours of Effective Stress

Figure 16: Minimum -  $3.59 \times 10^3$   
Maximum -  $1.37 \times 10^5$

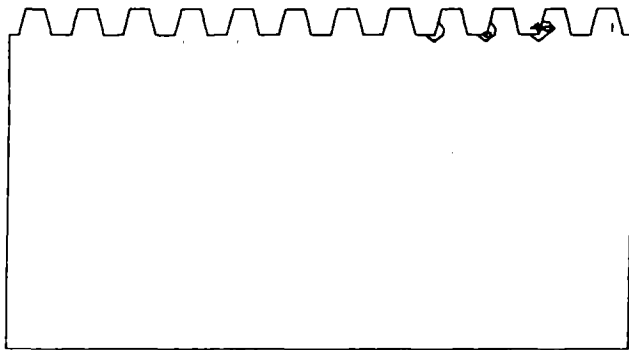
Figure 17: Minimum -  $4.49 \times 10^3$   
Maximum -  $1.41 \times 10^5$

Contour levels (both figures)

a = 0  
b =  $4.20 \times 10^4$   
c =  $8.40 \times 10^4$   
d =  $1.26 \times 10^5$



Rienecker—Figure 17



Rienecker—Figure 18

Contours of Effective Plastic Strain

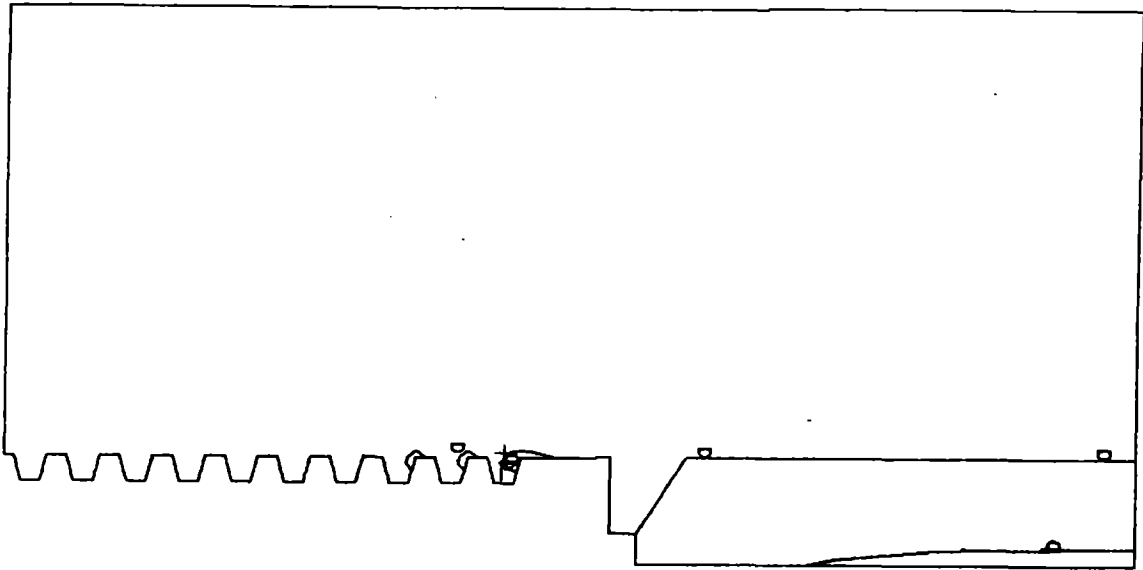
Figure 18: Minimum - 0  
Maximum -  $2.21 \times 10^{-3}$

Figure 19: Minimum - 0  
Maximum -  $3.32 \times 10^{-3}$

Contour levels

Figure 18: a = 0  
b =  $8.82 \times 10^{-4}$   
c =  $1.32 \times 10^{-3}$   
d =  $1.76 \times 10^{-3}$

Figure 19: a = 0  
b =  $1.33 \times 10^{-3}$   
c =  $1.99 \times 10^{-3}$   
d =  $2.65 \times 10^{-3}$



Rienecker—Figure 19

## ENGINEERING NOTE

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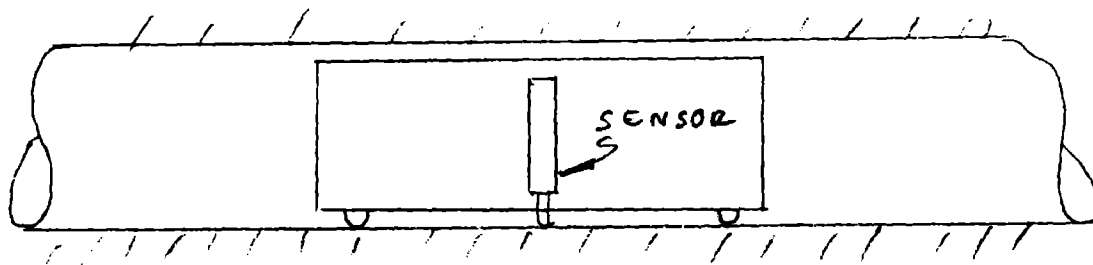
SUBJECT HEAF 6" GUN

NAME F. Richter

BORE CURVATURE

DATE 5/7/86

TO GAGE STRAIGHTNESS OF THE BORE IN THE SIX INCH GUN, WE WILL USE A 'RABBIT' TYPE OF A GAGE. IT WILL CONSIST OF A BRIDGE ONE FOOT LONG WITH A SENSOR AT THE CENTER TO MEASURE THE DEVIATION FROM STRAIGHTNESS.



THE GAGE WILL BE A REMOTE READING INDICATOR, SUCH AS AN LVDT. IT WILL BE MOVED ALONG THE BORE AND READINGS WILL BE CONVERTED TO RADIUS OF CURVATURE

AS A PROJECTILE FOLLOWS THE CURVE IN THE BORE, IT WILL EXPERIENCE A CENTRIFUGAL FORCE WHICH IS PROPORTIONAL TO THE CURVATURE AND THE VELOCITY SQUARED. THE BASIC EQUATION FOR RADIAL ACCELERATION IS

$$a_r = \frac{V_p^2}{R} \quad (1)$$

WHERE  $V_p$  = PROJECTILE VELOCITY m/s OR ft/s  
 $R$  = RADIUS OF CURVATURE m OR ft.  
 $a_r$  = RADIAL ACCELERATION m/s<sup>2</sup> OR ft/s<sup>2</sup>.

(UNITS MUST BE CONSISTENT)

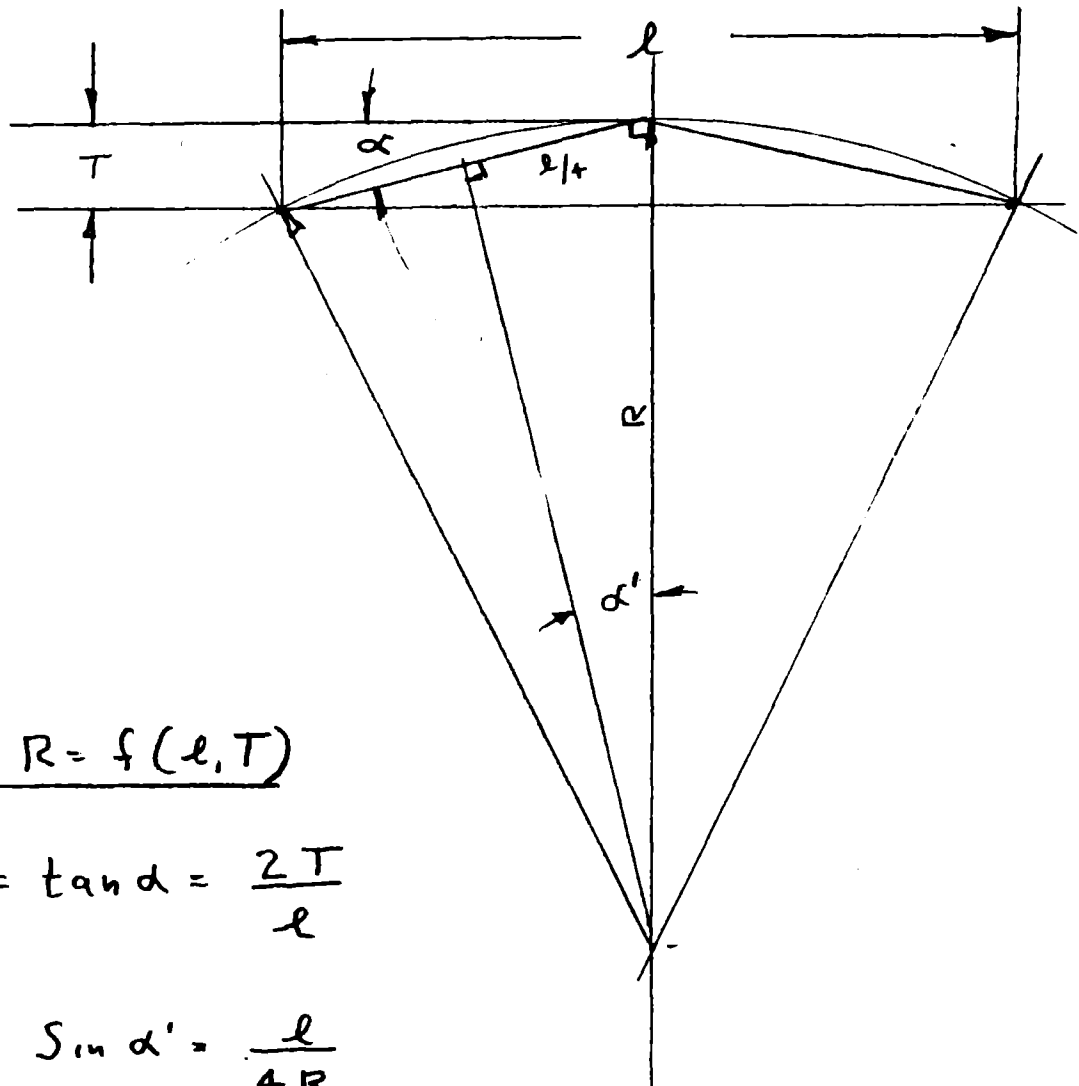
## ENGINEERING NOTE

SUBJECT HEAF 6" GUN

NAME Rienecker

BORE CURVATURE

DATE 5/7/86



TO FIND  $R = f(l, T)$

$$\frac{T}{l/2} = \tan \alpha = \frac{2T}{l}$$

$$\frac{l/4}{R} = \sin \alpha' = \frac{l}{4R}$$

By construction,  $\alpha' = \alpha$

FOR SMALL ANGLES,  $\sin \alpha = \tan \alpha$

$$\therefore \frac{l}{4R} = \frac{2T}{l}$$

$$\text{AND } R = \frac{l^2}{8T}$$

(2)

$$\text{(MORE PRECISELY, } R = \frac{l^2 + 4T^2}{8T}$$

BUT WITH  $T$  ON THE ORDER OF .001,  $T^2$  IS NEGLIGIBLE.)

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SUBJECT

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DATE 5/7/86

SUBSTITUTING (2) INTO (1)

$$a_v = \frac{8 T V_p^2}{l^2} \quad (m/s^2) \quad (3)$$

TO GET ACCELERATION IN G'S

$$a_r = \frac{8 T V_p^2}{l^2 g}$$

ASSUMING METRIC UNITS AND  $l = 1 \text{ ft} = .304 \text{ m}$ 

$$a_r = \frac{8 T V_p^2}{(.304)^2 9.8} = .8.833 T V_p^2 \quad (4)$$

THE RESULTS ARE PLOTTED IN FIG 1 FOR VARIOUS INDICATOR READINGS. IT IS CLEAR THAT THE BORE STRAIGHTNESS MUST BE THE BEST OBTAINABLE TO AVOID INTRODUCTION OF VERY HIGH LATERAL LOADS.

